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FINAL REPORT

SBIR CONTRACT NAS5-29274

ENTITLED

A NEW APPROACH TO LARGE AREA MICROCHANNEL PLATE MANUFACTURE

SUBMITTED TO NASA GODDARD SPACE FLIGHT CENTER

BY

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SEPTEMBER, 1986

TABLE OF CONTENTS

SECTION	PAGE

SUMMARY PAGE

PURPOSE: Detector Technology, Inc. invented a new method of manufacture for high gain microchannel plates for which it has patent pending. In order to establish feasibility and to facilitate initial development of this promising method from proof of concept toward practical and useful parameters, DeTech applied for and received NASA SBIR Phase I funding under contact NAS5-29274.

RESEARCH PERFORMED: DeTech has studied and evaluated methods of manufacture of twisted single elements as the base for producing microchannel plates. Two macroplates (MP's) with single pore construction were delivered to Dr. Gethyn Timothy at Stanford University. These detectors were tested by Dr. Timothy under NASA Contract NASW-4093 and NASA Grant NAG5-622. Work has begun on the construction of a MP boule with multi-pore single elements.

RESEARCH FINDINGS: Initial evaluations at Stanford have validated the off-axis channel concept and no technological roadblocks have been identified which would prevent fabrication of high gain, high spatial resolution, large format MCP's using this technique. The first MP's have operated at stable gains of $3x10^6$ with pulse height resolution superior to results obtained by standard chevron MCP's. In addition, DeTech has developed its own in- house manufacturing capability during Phase I, thus eliminating the need for outside engineering and manufacturing contributions. DeTech is positioned to control all processes in the further development of this product.

APPLICATION OF RESULTS: The progress, completed under Phase I, provides the initial foundation for future work aimed toward higher spatial resolution, reliable and repeatable fabrication techniques, lower costs, and manufacturing potential for larger format size detectors than the present high gain MCP manufacturing methods allow. With seperate funding thru Stanford on NASA Contract NHEW 5-622, DeTech will be able to maintain a continuity of effort in the interim between Phase I and Phase II. Phase I findings will be used to refine methods of manufacture of plates made with multipore elements during this period.

PHASE I - FINAL REPORT

PROJECT OBJECTIVES:

The history of microchannel plates as an imaging electron multiplier array, goes back to the early 1960's. The first products made by Bendix and Mullard were manufactured in standard small sizes. These detectors had straight channels which limited the gain to 10^3-10^4. The first high gain MCP's were developed by Bendix. These detectors consisted of a MCP pair with opposing bias angles, from which came the name Chevron. (Figure 1) The device required close proximity mounting of an MCP pair, with the built in problem of larger sizes creating more difficulty in mounting. It also suffers from a broad output pulse charge distribution, due to charge spreading to adjacent channels at the interface between the two MCP's.

Mullard developed a single high gain MCP which utilized a shearing technique to curve the channels to prevent ion feedback at gains above 10^4. (Figure 2) This method eliminates both problems noted above, which are related to the Chevron configuration. However, the eleven year history of the sheared plate has not yielded a product which has lived up to the initial promise. Fabrication costs are high, due to low yield. In many cases, (note that curvature control and curvature repeatibility is extremely difficult in the shear method) insufficient supression of ion feedback is noted. Also, the degree of manufacturing complexity increases rapidly with size, which has proven a major obstacle for formats over 40mm and rectangular or special MCP's.

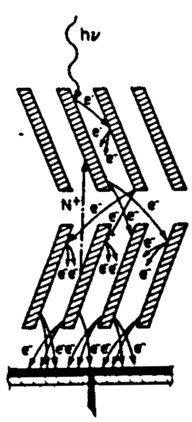

Figure 1 - Chevron

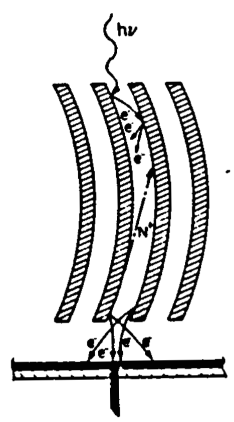

Figure 2 - Shear MCP

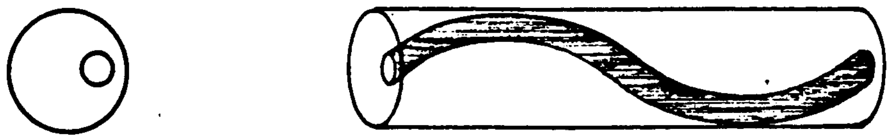

Figure 3 - Off-axis Single Element

During the year 1984, personnel at Detector Technology, Inc. invented a new method for the manufacture of feedback free microchannel plates. (MCP's) The central parameter of this invention is the production of channel curvature in a controled and repeatable method, ie, a draw tower operation. A crude reduction to practice, indicated that the method of utilizing an "off-axis pore" (OAP)(Figure 3) had promise, and a patent is now pending. The initial work was simply performed using large size pores in a single element approach. The one piece construction eliminates the Chevron problems. The use of the glass draw tower to introduce the individual channel curvature is the key which provides a great number of advantages over the shearing technique. The main assets are:

1. Uniformity of product. The draw process is a mechanically precise manufacturing method. With this process in control of the individual channel curvature, a precise slope to the curvature will remain throughout the draw.

2. Reproducibility of product. Closely related to uniformity is the goal of producing a product which can be repeated over and over in sister products which do not change operating characteristics. Again, the reproduction of the draw tower process on the channel curvature has been designed to be precisely controlled and all products will be the same.

3. Large format MCP. It is important to note that the method of curving will remain the same no matter what the MCP format size. Therefore curving will be no different, and will present no additional problems when comparing the manufacturing of a 125mm MCP to the manufacturing of an 18mm MCP.

4. Normal Processing. All normal and proven processing steps can be used on the OAP MCP during its manufacture. The sheared MCP on the other hand, requires a complete reheat of each MCP, a step which has a strong contribution to the low manufacturing yields associated with that product.

5. Reduction in cost. Taking into consideration the above items 1-4, the cost of manufacture will be reduced. As a direct result of the process repeatibility, it will also be well controlled.

All the above information on the "Off-Axis Pore" MCP indicated that the approach should be pursued. As a small business, reduction to present high gain MCP standards utilizing in-house funding couldn't be considered as a possibility. The NASA SBIR program provided an ideal funding source due to mutual interests, and a formal proposal was submitted and accepted. Proof of concept and further pursuit of the feasibility of construction of OA pores in a single "multi" extrusion was the principle objective of this Phase I project. Specifically, the following items were identified for work during Phase I:

1. Research and actual glass work was done to reduce pore sizes.

2. Produce MP's to be put through evaluation testing at Stanford.

3. Test these detectors at Stanford to establish a base line data and also to ensure feasibility of our initial processing capabilities.

4. Upgrade the "single element" from a one pore cross section to a multi-pore cross section

To present an organized report, these objectives will be treated as seperate subjects and reviewed in the same order in the following two sections.

WORK PERFORMED:

As originaly conceived, not all the objectives were reached due to a major change in the methods of working on Phase I. We originally quoted with the intent of purchasing a large amount of outside help including the services of Tom Loretz as a consultant. Almost to the day on which this contract was let, Mr. Loretz became a full time employee at DeTech. This presented the opportunity, at the cost of some Phase I progress, to work on the longer term goal of "re-establishing" original methods of manufacture in-house. We consider these steps as very significant progress toward succeeding work on the high gain, large area MCP. We are now in a position of in-house control on all the fundamental processes and costs for the planned development of this product.

1. Reduction of pore size.

Design work and reduction to practice was achieved in house for the manufacture of an MP with approximately 73 micron pores. These plates were made with one off-axis pore in the single "multi" element.

2. Production of MP's.

Work was carried out on perfecting the off-axis extrusion, and subsequent draw and twist of single "multi" elements. (Figure 4) A number of 18mm format MP's have been constructed, successfully core etched, processed and tested at DeTech. Two completed MP's (one with a length to diameter ratio of 60:1 the other with 80:1) were sent to Dr. Timothy at Stanford University for testing.

3. Tests at Stanford.

Upon receipt, Dr. Timothy evaluated both detectors under funding from a different NASA contract. Telephone conversations and a number of meetings were held with Dr. Timothy to review succeeding tests, to provide feedback and also to analyze results.

4. Multi-pore single element development.

The most important step to be taken was to reduce to practice the change from earlier work single pore "multi", to the more complex three or four pore multi. The completed cross-sectional design was evaluated, with attention paid to the conflicting considerations for maximum strength of the

finished single element versus the requirement of maximizing the potential open area ratio on the finished MP. The results of this study were drawn up and purchases were initiated. It is important to note that the majority of these purchases were tooling dies and molds for the extrusion step in MP or MCP manufacture. This equipment will be used in any succeeding efforts, and is functional on all pore sizes and for any MCP cross-sectional area.

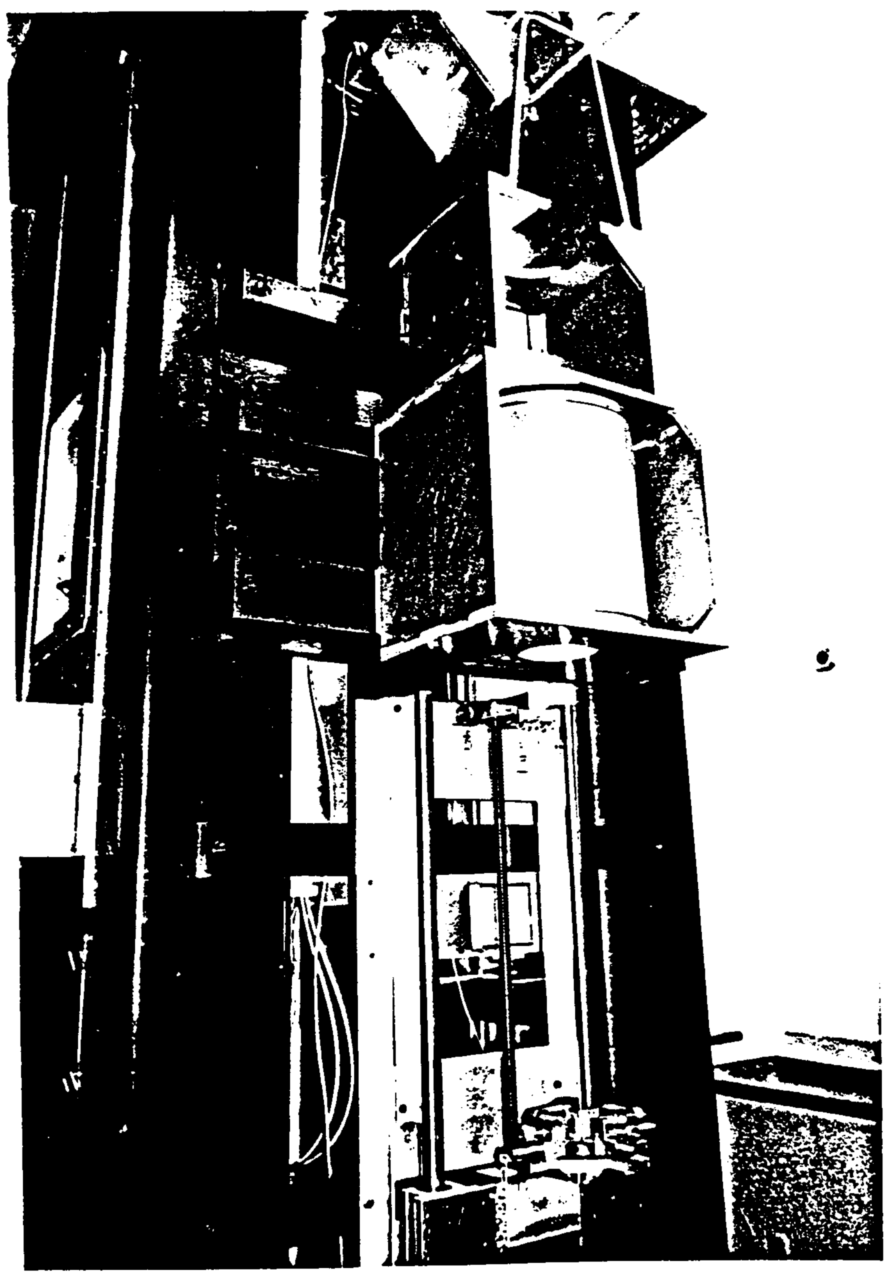

Figure 4 - Extruder

RESULTS OBTAINED:

The off-axis channel concept has proven to be a feasible approach to the manufacture of high gain MP's. The technology for fabrication on a larger pore size scale has been the first step in this development. The tests results are conclusively positive.

1. Reduction of pore size.

In-house design and construction resulted in a complete line of equipment and capabilities for the construction of smaller pore size MP's. DeTech, in a new Glass Technology Division, now has in-house glass manufacturing, glass extrusion, and glass draw capabilities. The design evaluation and manufacturing work has been completed for the production of 73 micron single pore element MP's.

2. Production of MP's.

As previously noted, 18mm MP's were sent to Dr. Timothy for testing. These detectors and others were successfully core etched, and preliminary tests were performed at DeTech with very satisfactory results. Evaluation of the detectors revealed that they behaved as expected, exhibiting good gain (above 10^6) and dark counts below .05cts/sec. There was little evidence of ion feedback, so the choice of a single twist per unit length appears capable of feedback supression.

3. Tests at Stanford.

The tests at Stanford have been carefully performed by Dr. Timothy, applying procedures and tests typical of previous work on other high gain MCP's. Extra care, caution, and observation steps were added due to the new product, larger than normal pore spacing and larger pore sizes. These results have been presented at the SPIE meeting in San Diego in August, and a preprint of the paper is found at the end of this report. Conditioning tests have progressed since the report was written, and the MP's continue to perform as expected. Dr. Timothy has baked plates to 105 degrees C and his next steps will be to bake and test after 200 degrees and then after 300 degrees.

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4. Multi-pore single element development.

To get from a single pore "multi" to a multi-pore single element involves working with specially designed extruder parts. Design of tooling and fixturing is complete, and the equipment has been assembled in-house. Photos of the extruder parts, and the four pore extruder die seat/die pin assembly in particular, are shown in Figures 5 and 6.

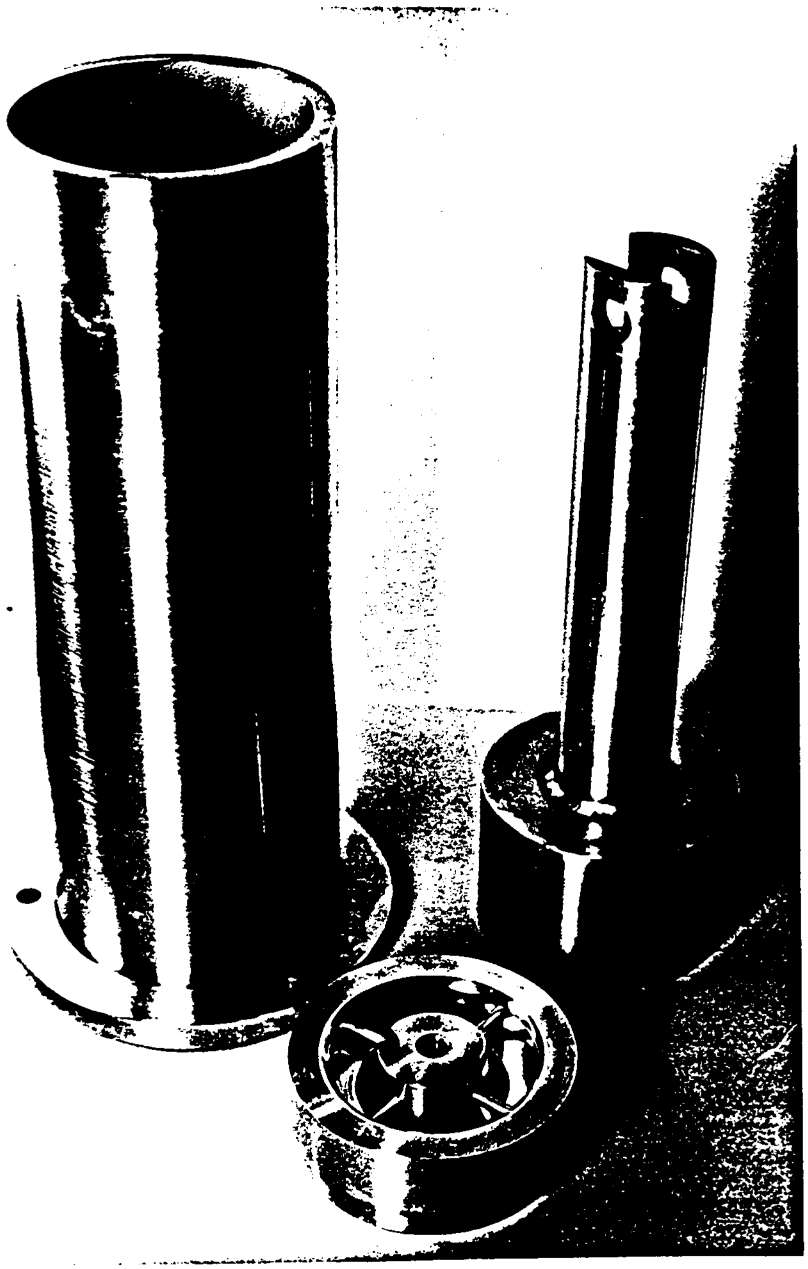

Figure 5 - Extruder die sleeve, piston, and die seat/die pin assembly.

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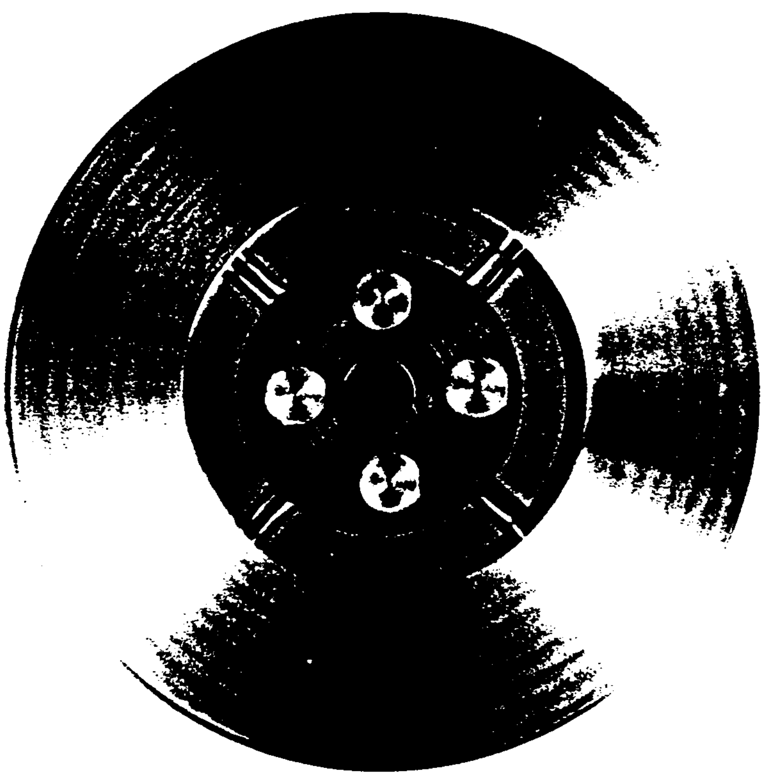

Figure 6 - Extruder die seat/die pin assembly

ESTIMATE OF TECHNICAL FEASIBILITY

At this stage in development, there is no manufacturing or test evidence which would dampen our enthusiasm for continuation of this program. It should be cautioned here, that the future steps required to produce small pore may reveal that these methods of manufacture are limited to large pore manufacture ie, 50 microns or larger.

DeTech is in the process of providing NASA with a proposal for Phase II. In the interim, work will progress under NASA project NHEW 5-622 which is funded to DeTech via Stanford, in order to maintain continuity of effort on product development. The main activity or goal of the interim program which is scheduled through January 1987, is to perfect the extrusion of a multi-pore single element. As much work as possible will also be done to reduce the pore size to 50 microns. MP's will be delivered to Stanford for the final test evaluation and corresponding technical feedback. Although these steps are complex and will require considerably more research than previous work, DeTech does not foresee any insurmountable problems.

Phase II would provide a program to reduce the pore size, increase the active area, maximize the open area ratio, and maintain spacial information from one face of the MCP to the other. The considerations and success estimate in each of these catagories, is evaluated below:

1. Pore size reduction.

A reduction in pore size to 12 microns will require a learning curve which relates to the motor mechanism utilized in the turning of the preform during the draw process. This area is projected as the area were the success of the program is the most vulnerable. In Phase I, a .250 inch diameter (6.3mm) preform was fed into a furnace at 1.0 in/min (25.4mm/min), while being spun at 40 RPM. It was subsequently drawn at 10.0 in/min (254mm/min) to a final diameter of 0.08in (2.0mm) with 4 twists per inch (.157 twists/mm). During the interim program and into Phase II, we plan to expand our knowledge and capabilities in the area of the four channel extruded preform. Much greater precision than that associated with Phase I will be required to ensure re-registration of the individual channels from plate face to plate face. Computer driven, micro-stepping motors, running at 25,000 (+-000) steps per revolution will be controlling the complete operation. Laser size monitors will provide data to sophisticated feedback control instrumentation to guarantee that critical diameter requirements are met.

Our Phase I results suggest that 12 micron pores can be attained it the starting preform can be diminished to a diameter approaching .060in (1.5mm) and spun at rates approaching 800 RPM. This would enable us to incorporate the requisite 21 twists per inch (approximately 0.83 per mm) for an L/D of 100:1 at reasonable feed and draw rates.

2. Increase active area.

Once the fibers are drawn, manufacturing to larger format MP's of MCP's will be done with the same methods presently used to make MCP's up to 5 inches. We also will be able to manufacture odd shapes which will be useful in other programs. (We are presently quoting an MP for use in an SBIR program at Amptek, Inc. which is a section of an arc). We forecast no insurmountable problems in this area, but an increase in size of an MCP historically can decrease yields considerably, and work will be required to reach larger formats which don't have such deadly yield factors built into the manufacturing process.

3. Maximize open area ratios.

To date, maximizing the open area ratio has not been a priority consideration. This has allowed ease of manufacture on the evaluation detectors. A major step in approaching accepted OAR values, will be undertaken with the multi pore single element approach. Other steps can be taken later. First, we may find the strength factor sufficient to allow an increase in the size of the pores in the single element. Secondly, MCP's are already being successfully etched to funnel the input. There is no reason why similiar techniques can't be used on an off-axis plate. We should be successful in achieving results on OAR which are the same as present manufacturing capabilities ie, 60% to 80% OAR.

4. Spatial resolution.

A problem unique to the off-axis manufacturing techniques is maintaintance of spacial resolution. Spatial resolution is dictated by the pore size and spacing. Steps must be taken to ensure that registration of a single pore is maintained from the input face to the output face. Again, the mechanical precision designed into the draw mechanisms contributes to an optimistic outlook. Test methods will need to be established, to utilize in quality assurance of the finished product.

CONCLUSION

DeTech would like to take this opportunity to express its appreciation to the SBIR Program and in particular NASA's SBIR Program for the opportunity to participate in the Phase I development program. We are proud of its success at a very low cost figure. MCP manufacturing has historically been a complex matter, but improvements can obviously be made.

Dr. Timothy's participation and interest has been an essential contribution to this success. His capabilities have allowed us to obtain a great variety of test data without the investment in time or money for a complex testing facility.

DeTech is now capable in both equipment and personnel to continue development of an off-axis MCP on an in-house basis. All the specific areas requiring further development are now controlled within our facility.

Presently, there are no obvious roadblocks to further progress and it is our corporate goal to follow up the success of the feasability study with further development, reduction to practice, and finally, the establishment of a unique and meaningful new product.

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The off-axis channel macroplate

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Abstract

High-gain microchannel plates (MCPs) which utilize curvature of the channel to inhibit ion feedback (C-plate MCPs) have demonstrated excellent performance characteristics. However, C-plate MCPs are at present costly to fabricate, and the shearing process used to curve the channels produces a low device yield. We describe here a totally new type of high-gain MCP structure in which each channel has an axially symmetric curvature. Initial tests of proof-of-concept units of these MCPs with 75-micron-diameter channels (macroplates) suggest that their performance characteristics have the potential to be equal to those of a C-plate MCP while the fabrication process is no more complex than that of a conventional straight-channel MCP.

Introduction

High-gain Microchannel Plates (MCPs) used to date have the configurations shown in Figure 1. "Chevron" and "Z-plate" MCP stacks, which are constructed from 2 or 3 MCPs having straight channels, are relatively easy to fabricate but do not have optimum performance characteristics. Even with bias angles of the order of 10 to 15 degrees, the trapping of positive ions at the interfaces of the plates is not completely effective, and there is a high level of residual ion feedback. In addition, spreading of charge at the interfaces degrades the spatial resolution of these MCP stacks when used with high-spatial-resolution readout systems. There is a further degradation of performance for high-resolution imaging systems caused by the broad pulse-height distributions of these MCPs at gain levels of the order of 10^6 to 10^7 electrons pulse^{-1}. The C-plate MCP, (Figure 1c), which employs curved channels to inhibit ion feedback in an identical manner to that used in a conventional channel electron multiplier (CEM), provides a high level of suppression of ion-feedback, a narrow output pulse-height distribution, and a very high spatial resolution. In particular, stable operation at gains in excess of 10^6 electrons pulse $^{-1}$, a resolution of the output pulse-height distribution of 30% or better, and a count rate capability in excess of 10^5 counts mm^{-2} s^{-1} have been realized with a single MCP with 12-micron-diameter channels on 15-micron centers.[1] Unfortunately, the shearing process required to introduce curvature into the channel is at this time difficult to control, the C-plates are at present costly to fabricate, and there is a low device yield.

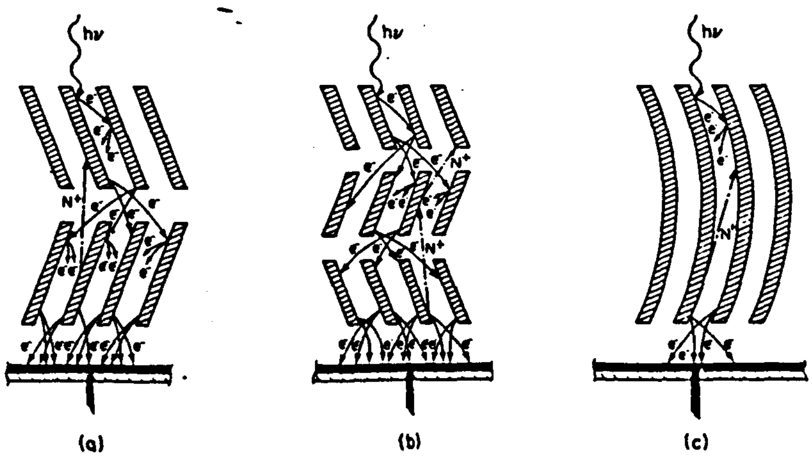

Figure 1. Configurations of high-gain MCPs.
a. "Chevron" MCP. b. "Z-plate" MCP. c. "C-plate" MCP.

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In this paper we describe the performance characteristics of proof-of-concept units of an MCP structure which employs an axially symmetric twist of the channel to produce the curvature required to effectively inhibit ion feedback. Since the curvature is built into the channel at the time of the fiber draw, the "off-axis channel" MCP (patent pending) is as simple to fabricate as a conventional straight-channel MCP, yet has the potential to provide the superior performance characteristics of the sheared curved-channel MCP.

The "off-axis channel" macroplate

The configuration of the "off-axis channel" electron multiplier is shown in Figure 2. One or more channels are fabricated off-center within a larger glass fiber. Twisting the fiber produces a helical channel with the appropriate geometrical form to inhibit the trajectories of positive ions.

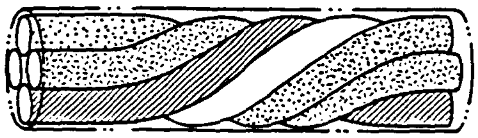

Figure 2. Configuration of the "off-axis channel" electron multiplier.

In order to produce a high-gain MCP with channels of this configuration, a number of requirements must be met. First, there must be about three or four channels per fiber in order to produce an open-area ratio equivalent to that of a conventional MCP. Second, for imaging applications, there must be an integral number of twists across the thickness of the plate in order to preserve the spatial relationship of the channel inputs and outputs. Third, in order to get at least one complete twist in a channel with a final diameter in the range from 10 to 25 microns, there must be a very high twist density in the original fiber.

As the first step in evaluating the "off-axis channel" concept, we have fabricated a number of 18-mm-format macroplates with active areas 15 mm in diameter and channel diameters of 75 microns. For ease of fabrication these proof-of-concept units employ only one channel per fiber, yielding a low open-area ratio of about 15%. Fibers of the type used to fabricate the macroplates are shown in Figure 3. Two macroplates have so far been tested, the first with a channel length-to-diameter ratio of 60:1, and the second with a channel length-to diameter ratio of 80:1.

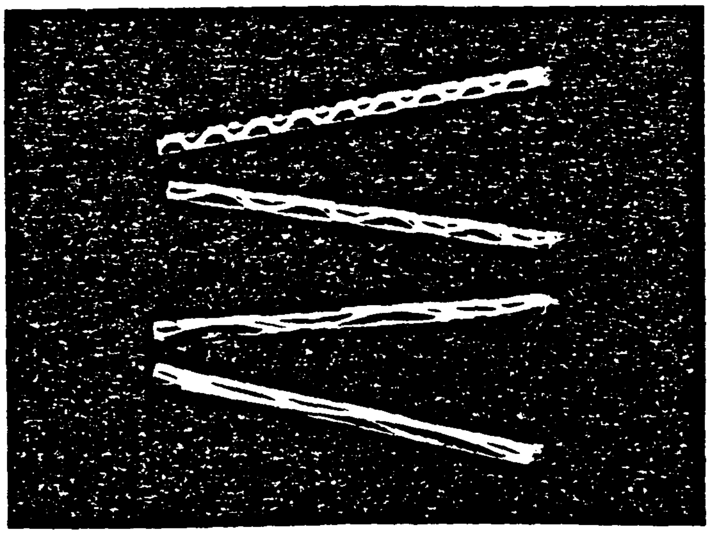

Figure 3. "Off-axis channel" fibers with different twist densities.

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Performance Characteristics

Before evaluation both macroplates were subjected to bake and "scrub" procedures similar to those that we have developed for the C-plate MCPs.[1] However, because these macroplates employ channels of a totally new type, the evaluation program is being carried out in stages. For the initial tests, the first macroplate was baked in a hydrocarbon-free high-vacuum environment at a temperature of 120°C for a period of 24 hours and the second at 110°C for a period of 5 hours. Ultimately, the macroplates will be baked at 300° C until a pressure asymptote is attained. Each plate was "scrubbed" by operating it in a demountable MAMA detector tube[1] with the input face illuminated with ultraviolet photons from a mercury "penray" lamp. A total signal of 4×10^{10} counts, equivalent to a charge throughput of 0.01 C was accumulated before the initial evaluation. The resistances of the two macroplates were 25 MΩ and 31 MΩ respectively. In operation at an applied potential of 2400 V the strip current increased by about 12%, indicating that the temperature of the plate had increased by about 25 degrees C because of ohmic heating. However, no operating instabilities were observed.

The performance characteristics of both macroplates were very similar, with the exception that the resolution of the output pulse-height distribution (defined as $R = \Delta G/\bar{G}$ where ΔG = full width at half-height of the distribution and $\bar{G}$ = gain value at the peak of the saturated distribution) was somewhat superior for the plate with a channel length-to-diameter ratio of 80:1. Both macroplates demonstrated gain saturation at applied potentials in excess of 2000 V. The variations of the modal gain and the resolution of the output pulse-height distribution as functions of the applied potential are shown in Figure 4.

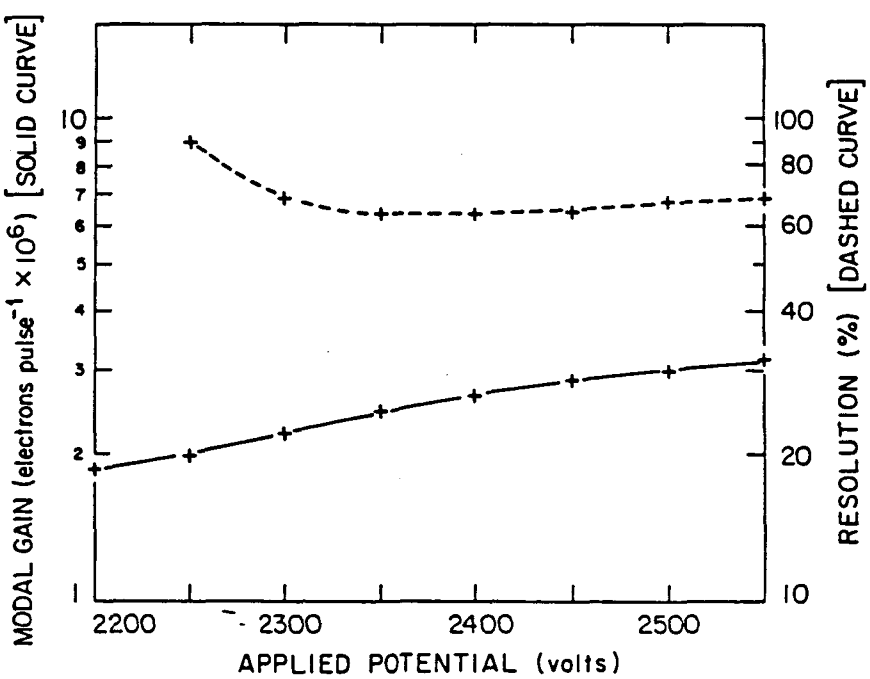

Figure 4. Variations of the modal gain and the resolution of the output pulse-height distribution as functions of the applied potential for the macroplate with an 80:1 channel length-to-diameter ratio. Macroplate was stimulated by 2537 A photons.

The saturated form of the output pulse-height distribution (see Figure 5) clearly demonstrates that the helical form of the channel is effective in suppressing ion feedback at high gain levels. The best resolution of the pulse-height distribution for the macroplate with a channel length-to-diameter ratio of 80:1 (~64%) is superior to the values that we have obtained in the past with "Chevron" and "Z-plate" MCP stacks.[2] The macroplate with a 60:1 channel length-to-diameter ratio yielded essentially identical gain values but the best resolution was about 71%. A further indication of the high level of suppression of ion feedback is the very low dark count rate (~0.3 counts s^{-1} for the total active area).

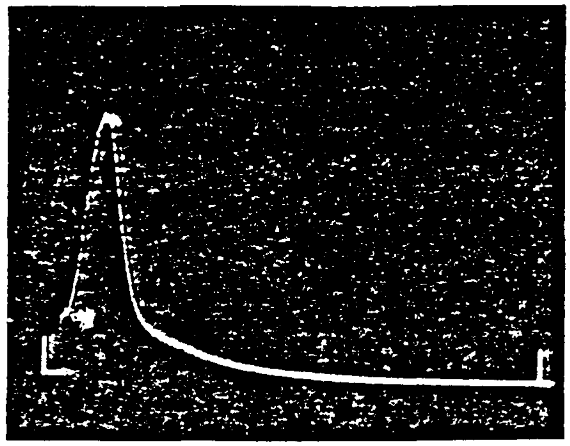

Figure 5. Output pulse-height distribution for macroplate with 80:1 channel length-to-diameter ratio at an applied potential of 2400 V. Modal gain 2.6 x 10^6 electrons pulse^{-1}, resolution 63.5%.

One immediate difference between the performance of the macroplate and that of a conventional MCP is the very strong dependence of the macroplate detection efficiency on the electrostatic field strength at the input to the channels which is caused by the low open-area ratio. The macroplate was operated with the input face at a high negative potential and the output face at ground. By applying a higher negative potential on a focusing electrode mounted in front of the macroplate, photoelectrons liberated on the front-face electrode could be directed into the channels. As shown in Figure 6, the collection efficiency was a very sensitive function of the applied potential. Further, the focusing electrode potential for maximum detection efficiency varied with the distance from the center of the macroplate.

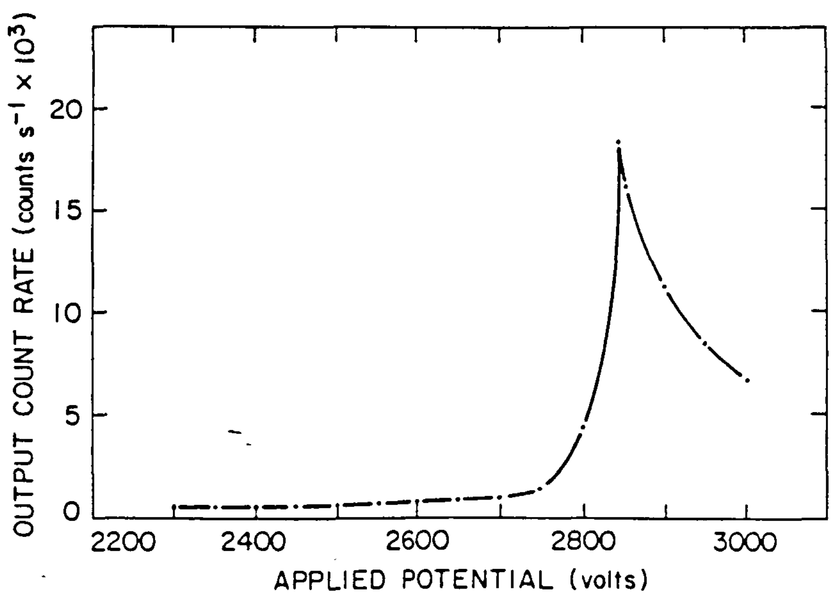

Figure 6. Variation of the macroplate output count rate as a function of the focusing electrode potential. Macroplate input face potential 2400 V. Both electrodes operated at negative potentials with respect to ground. Center of macroplate illuminated with 2537 A photons.

Since the increase in the detection efficiency is significantly greater than the closed-to-open area ratio, it is clear that there is a low detection efficiency within the channels which is almost certainly caused by the combination of the zero bias angle of the channels and the collimated input beam. No significant gain changes were observed as a function of the field electrode potential. When the collection efficiency was optimized by applying a suitable focusing electrode bias potential (typically in the range from 280 to 350 V negative of the macroplate input face potential), the variation of the output count rate as a function of the macroplate potential had the form shown in Figure 7.

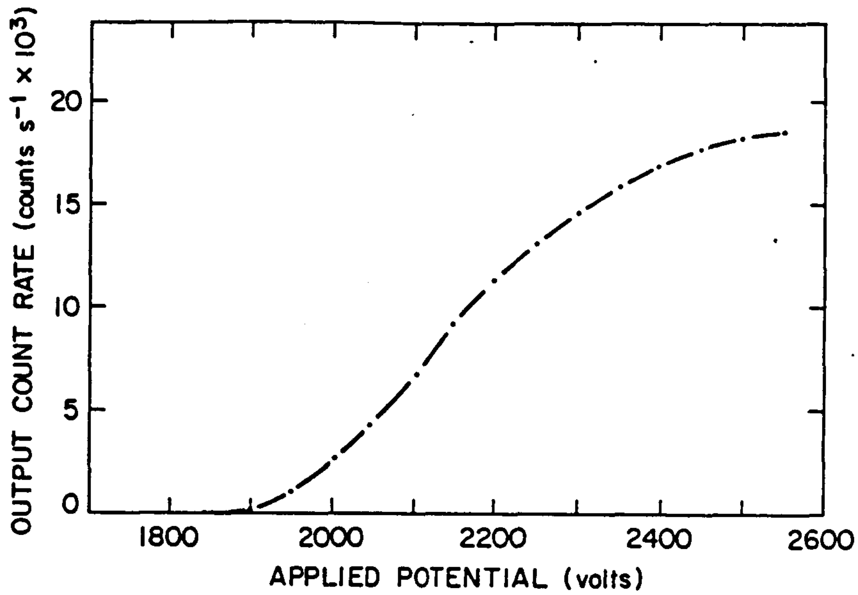

Figure 7. Variation of the output count rate as a function of the macroplate potential. Focusing electrode potential set for maximum detection efficiency. Center of macroplate illuminated with 2537 A photons.

The shape of this curve shows the characteristic plateau obtained with a high-gain channel multiplier providing a saturated output pulse-height distribution.

In summary, the data from the initial evaluations show clearly that the "off-axis channel" is effective in suppressing ion-feedback and that this structure can be used to construct a high-gain MCP.

Future Developments

With the "off-axis channel" concept validated, the need now is to demonstrate that this technology can produce a high-gain MCP with a channel diameter in the range from 10 to 25 microns and an open-area ratio of greater than 50%. The next step in the development program will be to produce sample MCPs with 25-micron channel diameters. The first units will again employ a single channel per fiber. Following this, the first MCPs with multiple channels per fiber will be fabricated, starting with large channel diameters and working down to diameters in the range from 10 to 25 microns. As soon as the first MCPs are available, imaging tests will oe initiated to verify that the spatial relationship of the channel inputs and outputs can be maintained.

Acknowledgments

We are happy to acknowledge the support that we have received from Dr. E. J. Weiler at NASA Headquarters and from Mr. F. Rebar and Dr. B. E. Woodgate at the NASA Goddard Space Flight Center. This development program is supported at Stanford University by NASA Grant NAG5-622 and NASA Contract NASW-4093 and at Detector Technology Inc. by NASA Small Business Innovative Research Program Contract NAS5-29274.

References

1. Timothy, J. G., "Curved-channel microchannel array plates," Rev. Sci. Instrum. 52, pp. 1131-1142. 1981.

2. Timothy, J. G., "Preliminary results with saturable microchannel array plates," Rev. Sci. Instrum. 45, pp. 834-837. 1974.